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Microbiological Process Report

Activity of Microorganisms in Organic Waste Disposal

IV. Bio-Calculations[1]

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Principles of aerobic and anaerobic treatment of organic wastes were developed in the previous papers of this symposium. The application of these principles to engineering design is discussed in this paper. Although the discussion is restricted to the aerobic treatments, the concepts are equally applicable to anaerobic treatments.

Laboratory or pilot plant studies are employed to develop engineering design criteria. Laboratory studies are usually batch treatment operations in which various concentrations of acclimatized sludge are aerated with known quantities of waste. Changes in pertinent characteristics such as BOD, COD, oxygen utilization, and sludge accumulation are noted with time. Relationships between time and concentration can be developed from such data.

A pilot plant treats waste continuously, simulating anticipated plant scale operation. Variables such as organic matter loading, air rate, and microbial sludge content are changed under conditions of steady state operation. Pilot plant data statistically analyzed provide a sound basis for scaling up to process design.

Bio-Oxidation Processes

Bio-oxidation systems may be broadly classified into two categories: the fixed bed or trickling filter and the fluid bed or activated sludge. These two systems may be sub-classified into various modifications.

The trickling filter is a system in which the organic waste is distributed over microbial growths attached to a stone or other media. As the water passes through the filter, the time of contact with the biological slimes is 15 to 25 min; hence, it is probable that the initial reactive capacity of the filter slimes for the waste exerts a major influence on filter performance. Treatment performance is further enhanced by recirculation of the effluent, thus permitting the organic matter to contact the filter films more than once.

Oxygen is transferred to the films from air drawn into the filter bed due to a temperature gradient between the waste and the ambient air and also from oxygen dissolved in the incoming waste. Figure 1 is a schematic presentation of a trickling filter.

Activated sludge processes are systems in which microbial growths are continuously circulated and contacted or mixed with organic waste in the presence of oxygen. The oxygen is usually supplied from air bubbles injected into the mixing sludge-liquid mass under turbulent conditions. The process basically involves an aeration step followed by a solids-liquid separation step from which the separated sludge is recycled for admixture with fresh waste. A batch treatment process has recently been developed in which waste is added to the system for a part of a day followed by sedimentation and decantation (Kountz, 1954). A balance is attained to minimize excess sludge production in the system.

Design Factors

Primary variables important in the design of continuous systems are:

(a) Aeration detention period required to convert a specified loading of organic matter to a predetermined stabilized level.
(b) Oxygen demand rates and air requirements.
(c) Sludge accumulation and disposal.
(d) Nutritional requirements.
(e) Solid-liquid separation.

Aeration Detention Period

The assimilation of organic matter by microbial growths is a time-concentration phenomenon. Therefore, it may be generalized that the efficiency of BOD removal in the activated sludge process is a function of the aeration time, the concentration of active sludge solids and the BOD loading. The efficiency may be related to a loading factor involving the aforementioned variables (Eckenfelder and O'Connor, 1954; Fair and

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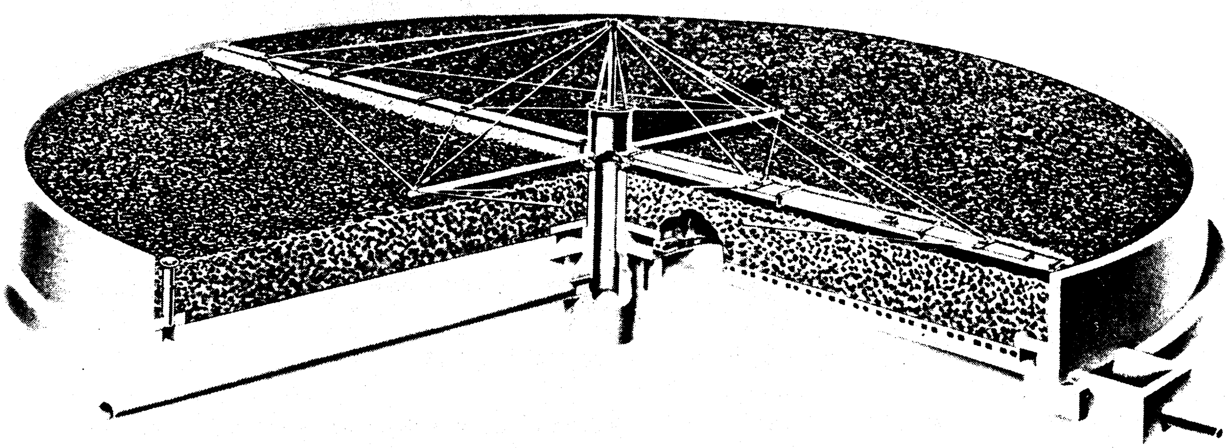

FIG. 1. Schematic presentation of a trickling filter (Courtesy of Dorr-Oliver, Inc.)

TABLE 1. *BOD reduction of organic wastes by activated sludge*

Waste	Process	BOD Loading		Mixed Liquor Sludge Solids Ppm	Aeration Time	Return Sludge	BOD Reduction
		lb day, lb MLSS	ppm		*hr*	*per cent*	*per cent*
Sewage*	Conventional	0.228	153	2050	6.34	35	90
Sewage*	High rate	2.08	132	530	2.92	20	67.5
Pulp and paper†	Conventional	0.30	183	2910	3.85	33	91.2
Pharmaceutical‡	Conventional	1.60	1556	3292	3.75	100	89.0
Cannery§	Conventional	2.56	630	2500	4.8	—	81.6
Cannery¶	Contact stabiliz.	1.28	600	3220	3.0	100	84.0

* Haseltine, 1955.
† Eckenfelder and Moore, 1954.
‡ Dryden *et al.*, 1955.
§ Eckenfelder and Grich, 1955.
¶ The BOD loading to the aerator alone is 12.4 lb BOD/day/lb sludge and is principally cell storage (Eckenfelder, 1952a).

Thomas, 1950; Haseltine, 1955). This loading factor is expressed: lb BOD per day per lb aeration sludge. When pilot plant operation approximates desired conditions this loading factor may be employed as a primary design criterion. In present practice, aeration detention periods vary from 1 to 8 hr while the mixed liquor sludge solids concentrations vary from 1000 to 4000 ppm.

In treatment of domestic sewage employing conventional activated sludge, 90 per cent BOD reduction has been obtained with loading factors varying from 0.1 to 0.5 lb BOD per day per lb aeration sludge. Similar reduction in BOD has been obtained by oxidation of Kraft mill waste with a loading factor of 0.3. Table 1 shows some typical performance data.

Garrett and Sawyer (1952) used glucose and peptone and obtained maximum removal rates of 3.6 lb of BOD per day per lb solids at 10 C, 11.6 lb of BOD at 20 C, and 20.8 lb at 30 C. Lower maximum removal rates have been observed in the treatment of pharmaceutical and cannery wastes.

The loading factor is expressed in terms of mixed liquor suspended solids for convenience. Since only a portion of the sludge may be considered as active culture (Hoover *et al.*, 1951), BOD removals observed for a particular system are representative only of that specific waste. In some cases volatile suspended solids will provide a better correlation than total suspended solids. An example from a pulp and paper waste oxidation may be cited. The sludge was 85 per cent volatile but, due to the presence of biologically inert fiber and other volatile solids, the computed active fraction was only 70 per cent. This active fraction was variable depending upon the detention time and fiber load on the process.

The loading factor employed for a process design should consider the total time the sludge mass has been undergoing aeration. Some process modifications, such as contact stabilization, employ a short aerating contact period of the waste with sludge for rapid removal of BOD (principally as storage) followed by a relatively longer period of aeration of the resulting sludge for oxidation and synthesis (Porges *et al.*, 1955). The loading factor computed for waste aeration alone is primarily representative of storage, while the loading factor based on the entire waste and sludge mass involves all steps of the process.

Loading-efficiency data for any particular waste must be obtained by experimental investigations on that waste using well acclimated sludge. The loading that can be applied to the sludge or the amount of organic matter stabilized is related to various secondary factors that influence the performance of the over-all process. Many investigators have interpreted these factors in terms of sludge age which in turn is related to the length of time the sludge has been undergoing aeration. Sludge age may be generally considered as the reciprocal of the loading factor. Gould (1953a) defines sludge age as the ratio of the mixed liquor suspended solids to the suspended solids per day in the raw sewage. A more fundamental interpretation of sludge age was advanced by Gellman and Heukelekian (1953) who consider it as the ratio of the mixed liquor suspended solids to the lb BOD removed per day in the system.

Edwards (1949) and Gould (1953b) showed the conventional process to have a sludge age of 3 to 4 days in summer, and 0.4 days in winter. Poor settling properties were obtained over the range of 0.5 to 3.0 days.

Interesting studies by McKinney (1955) indicated that, at high loading factors, sludge does not flocculate but rather functions as a dispersed growth. Only when the sludge approaches the endogenous phase does flocculation occur. Flocculation of biological sludge is therefore interpreted as a function of the energy content of the system and occurs when the latter is relatively low. Busch and Kalinske (1955) attributed nonflocculant properties (poor settleability) to a young sludge population in the log growth phase. While there is some doubt as to interpretation of the effects of high loadings on the performance of the over-all process, it is generally conceded that sedimentation and compaction of sludge are impaired when high loading factors are employed.

When the BOD loading per unit time is plotted against the BOD removal per unit time, a curve is obtained in which, within limits, the removal approximates a linear function of the loading. At high loadings the removal approaches a limiting value so that increased loadings substantially affect no further reduction.

Similar loading factors may be employed for the design of trickling filters. Since exact measurements of the quantity of active sludge solids are impractical, the loading factor is usually expressed as lb of BOD per day per cu yd of media. Maximum observed removals in filter operation are 3.1 to 3.3 lb of BOD per day per cu yd producing an over-all process efficiency of 25 to 35 per cent (Fischer, 1942; Walton, 1943; Velz, 1948). Since the quantity of available sludge in a filter varies from 8 to 12 lb per cu yd for low rate filters and 5.5 to 11 lb per cu yd for high rate filters (Heukelekian, 1945), the maximum removals are 0.2 to 0.4 lb of BOD per day per lb sludge. In polystyrene filter media recently developed (J. R. Bryan, Personal Communication), 4.6 lb of sludge of 70 per cent volatile solids content was found per cubic yard of media. The sludge film varied from $1/16$ to $1/8$ in in thickness.

Oxygen Demand Rates and Air Requirements

Oxygen plays an essential role in aerobic biological treatment and must be supplied at a rate equal to or greater than its rate of utilization for optimum efficiency. Oxygen utilization may be defined as the weight of oxygen consumed by a given weight of microbial sludge per unit of time. It is usually expressed as ppm O_2 per hr per g sludge.

A linear relationship will exist between the sludge concentration and the oxygen utilized over the range of sludge concentration usually employed (Eckenfelder, 1952b, c; Hixon and Gaden, 1950). In very high sludge concentrations (> 10,000 ppm) the unit rate of oxygen utilization may decrease due to diffusional resistances (Dawson and Jenkins, 1949).

The oxygen utilization rate characteristics of a sludge-liquid mass is defined by the quantity of unoxidized organic matter present (nutrient) and the growth phase of the sludge (assimilation or endogenous respiration). Active respiration occurs in the presence of sufficient food and oxygen to produce energy for the assimilation of organic matter. In addition to the above oxidation, the sludge produced by the assimilation of organic matter is continually oxidized by its own mass. Hoover and Porges (1952) define this as endogenous respiration. Endogenous respiration is frequently defined as the per cent oxidation per day of the sludge solids under aeration. This would correspond to a constant rate of oxidation per unit of sludge. Actually the oxidation rate decreases with time due to the fact that the cell constituents differ in their ease of oxidation, and for many microorganisms is a logarithmic decline.

The total oxygen requirements for a biological system may be related to the quantity of organic matter removed and the concentration of sludge solids according to Eq. 1 and illustrated on figure 2.

$$\text{ppm } O_2 = (1\text{-}a)L_r + bS$$

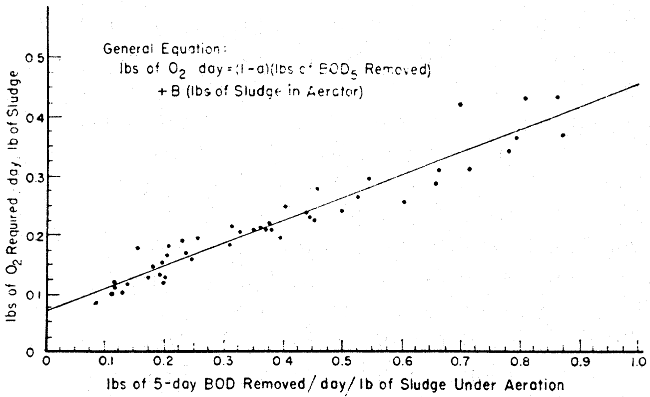

Fig. 2. Relation between oxygen consumption and BOD removal for a paper mill waste.

In this equation:

a = that part of the BOD removed from solution for synthesis
$1\text{-}a$ = part of removed BOD oxidized
L_r = total BOD removed in ppm
b = rate of endogenous respiration, per cent per day
S = sludge solids in ppm

The constants for this relationship must be experimentally evaluated for any particular waste. Caution must be exercised in the interpretation of Eq. 1 when organic matter (BOD) is stored in the sludge system as this relationship is based upon a synthesis-oxidation balance. A similar relationship was derived by Smith (1952) for the oxidation of domestic sewage.

Sludge cells tend to clump, hence decreasing the quantity of oxygen that can be transferred to them by increasing resistance to transfer. Hober (1945) and Pasveer (1954) defined a mathematical relationship for oxygen diffusion into microbial cells which is a function of floc size, diffusivity, oxygen utilization rate, and external concentration of dissolved oxygen (driving force). High degrees of agitation will disperse the sludge clumps and increase the transfer rate to the cells for metabolism. By decreasing the mean floc radius, a greater surface is exposed for oxygen transfer and the degree of oxygen penetration is increased. This results in increasing the unit rate of oxygen utilization. The maximum turbulence desired in a system may be defined as that power input which will not excessively shear the floc particles and will not prevent subsequent settling. Turbulence and power input to the aeration system is frequently expressed as horsepower absorbed per 1000 gallons of tank capacity.

Air requirements to the activated sludge process are dictated by the oxygen utilization requirements of the process, the physical and chemical properties of the waste to be aerated, and by the gas-liquid absorption properties of the aerating device. The oxygen absorption capacity of wastes will differ from that of pure water due to changes in surface tension and viscosity. Depending on the specific nature of the wastes, absorption may be as low as 20 per cent of that of water under standardized aeration conditions.

Bio-oxidation alters the physical and chemical properties of waste mixtures, and modifies the transfer capacity to a value approaching that of water. During activated sludge treatment of domestic sewage, 4-hr aeration increased the oxygen transfer capacity from 72 to 90 per cent of that of water. High mixed liquor solids concentrations in the activated sludge process reduced the transfer capacity by altering the physical properties of the aerating medium. In the presence of 10,000 ppm sludge, absorption was only 20 per cent of that in pure water (Gaden, 1949).

In the long rectangular aeration tanks used in conventional activated sludge practice, the sludge-liquid mixture is rolled down the tank length with a spiral motion imparted by the air. As the BOD in the influent waste undergoes oxidation and synthesis, the oxygen utilization rate decreases and approaches that of the endogenous level toward the end of the aeration basins. Figure 3 shows the plot of a typical utilization curve. (A variable utilization rate will usually not be found in square or circular tanks since the homogenizing effect of the agitation and aeration tends to equalize the utilization rate at a mean level.)

Tapered aeration takes economic advantage of this decreasing utilization rate through the aeration tanks. Oxygen absorption can be adjusted to meet the necessary demand by reducing the number of individual aeration assemblies along the tank length or by regulating the rate of air flow at each point in the aeration tank by appropriate valving.

Three basic types of aeration devices are commercially available. Porous type orifice diffusion units are (1) plates or tubes constructed of silicon dioxide or aluminum oxide grains held in a porous mass with a ceramic binder and (2) saran or nylon wrapped tubes or bags. These units are permanently placed in the bottom of an aeration tank or are suspended from

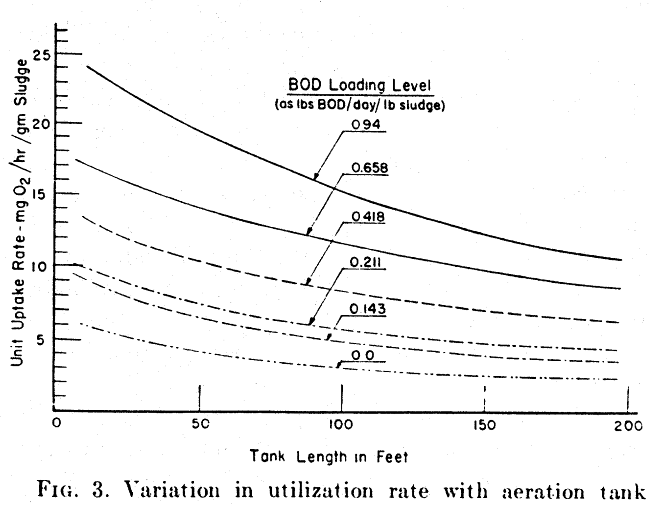

Fig. 3. Variation in utilization rate with aeration tank length and BOD loading level.

flexible joints along the sidewall of a tank. When air is diffused through these units, a helical or screw motion is imparted to the sludge-liquid mixture. The second type represented by the impingement or jet aerator employs mechanical or air shear.

The third type consists of mechanical aerators which entrain atmospheric oxygen into the sludge by surface agitation or disperse compressed air by a shearing and pumping action employing a rotating turbine or agitator. In the latter, air is discharged from a pipe or sparger ring placed beneath the agitator and is broken up by the shearing action of the high-speed rotating blades moving through the liquid. As the speed of the impellor is increased, the bubble size is decreased, thus increasing the total interfacial area. For systems requiring low oxygen utilization rate, oxygen may be supplied by air, self-induced from the negative head produced by the rotor, thus eliminating the necessity for external blowers or compressors.

The orifice and air-liquid shear units have an absorption efficiency of 5 to 15 per cent in pure water at air rates of 4 to 12 standard cubic feet per minute per unit. Power requirements may be expected to vary from 0.2 to 0.4 kilowatt per hr per lb oxygen transferred to the solution. Mechanical aerators will exhibit higher efficiencies at increased power levels (Eckenfelder, 1955; Kountz and Villforth, 1954).

Sludge Production

The quantity of bacterial sludge produced will be proportional to the BOD removed in the process. Additional sludge for disposal will be contributed by inert suspended solids present in the waste. The composition of the sludge in an oxidation system may consist of microbial protoplasm, nonoxidizable organic matter, organisms and inorganic solids. The quantity of microbial sludge produced by a system can be estimated by the following material balance:

$$\text{Excess biological sludge} = aL_r - bS \qquad (2)$$

The value, a, has been found to vary from 50 to 75 per cent of the BOD removed by the system assuming no storage. Hoover *et al.* (1951) and Sawyer (1955) show that the expected growth of new sludge is 50 to 60 per cent of the dry weight of organic food. Gellman and Heukelekian (1953) obtained a yield of 0.5 lb of volatile solids per lb BOD fed to the system.

The presence of inert suspended solids removed in the system will increase the total quantity of sludge for disposal and Eq. 2 should be modified.

$$\text{Excess sludge} = aL_r - bS + C \qquad (3)$$

in which C = inert suspended solids. The portion of the sludge which will be consumed in the process by oxidation (endogenous respiration) will be a function of the solids concentration and the time of aeration. At lower temperatures the rate of endogenous respiration is reduced and less of the synthesized sludge is oxidized.

Nutritional Requirements

Efficient and successful biological oxidation of organic wastes requires a minimal quantity of nitrogen and phosphorus for the synthesis of new cell tissue. In addition, trace quantities of several other elements such as potassium and calcium are required. These elements are usually present in natural waters in sufficient quantity to satisfy the requirements for bacterial metabolism. Nitrogen and phosphorus, however, are frequently deficient in waste substrates and must be fed as a nutrient supplement to the system to attain optimum efficiency.

The nitrogen cycle in biological waste treatment is shown below:

$$\begin{array}{l} \text{Organic nitrogen} \\ \qquad\downarrow \\ \text{BOD} + NH_3 + O_2 \dashrightarrow \text{Bacterial cells} + CO_2 + H_2O \\ \qquad\qquad\qquad\qquad\qquad (\text{Organic nitrogen}) \\ \qquad\qquad\qquad\qquad\qquad \downarrow + O_2 \\ \qquad\qquad\qquad\qquad\qquad NH_3 + CO_2 + H_2O \\ \qquad\qquad\qquad\qquad\qquad \downarrow + O_2 \\ \qquad\qquad\qquad\qquad\qquad NO_2 \\ \qquad\qquad\qquad\qquad\qquad \downarrow + O_2 \\ \qquad\qquad\qquad\qquad\qquad NO_3 \end{array}$$

As may be observed, some nitrogen will be reused in the system due to the oxidation of cell tissue by endogenous respiration with the release of ammonia into the solution

Nitrogen and phosphorus are important constituents of microbial cell structure and are present in the proteins and amino acids. Cell nitrogen will vary from 6 to 15 per cent and phosphorus from 2 to 5 per cent on a dry weight basis for most microorganisms of importance in waste treatment practice. Studies by Helmers *et al.* (1952) showed that for optimum process efficiency a minimum nitrogen content of 7 per cent and a minimum phosphorus content of 1.2 per cent by weight of the total volatile solids should be maintained. Recent investigations by Porges *et al.* (1955) revealed that, while the cell nitrogen was 12 to 14 per cent in the endogenous phase, storage of BOD in the active growth phase reduced the nitrogen content to 7 per cent.

Nitrogen in the form of ammonia and some forms of organic nitrogen are available to the organisms for synthesis. Soluble inorganic phosphorus and most organic phosphorus are available for microbial usage. When a nutritional supplement is required for a biological process, ammoniacal nitrogen and soluble phosphorus salts are generally used since they are most readily assimilable. It is usually not advisable to add nitrates because they may serve as a secondary source of oxygen in settling tanks where the available dissolved oxygen may be depleted. Nitrates are reduced and nitrogen gas is formed causing a floating sludge.

Many activated sludges contain an appreciable inert and amorphous fraction hence the nitrogen content may be quite low. For example, a biological sludge from a pulp and paper waste containing a large percentage of stable organic matter had a nitrogen content of 3.5 per cent based on the total volatile solids. By comparison, the nitrogen content of an average domestic sewage biological sludge is 7.5 per cent based on the total volatile solids.

Nutritional requirements may be expressed as a fraction of the total volatile solids, as lb of N or P per 100 lb BOD removed in the process or as BOD to N or BOD to P ratios. Nitrogen and phosphorus requirements may be more rigorously computed from a material balance based on the maintenance of a minimum nitrogen and phosphorus content in the biological sludge produced in the system. Nitrogen is fed to a system as a gas (anhydrous ammonia), as aqueous ammonia, or as dry ammonium salt. Phosphorus may be added as a solution of phosphoric acid.

Solid-Liquid Separation

Solid-liquid separation is an integral part of any biological oxidation system. The primary function is to separate the biological growths from their associated treated liquor for return to the aeration process or for subsequent disposal steps. Separation can be achieved by sedimentation or by dissolved air flotation. The selection of method depends on economic or process considerations.

Sedimentation

When sedimentation is employed the concentration of active sludge solids which can be maintained in the aeration basins is limited by the settling and compaction characteristics of the biological sludge in secondary settling tanks.

In a continuously operating settling tank, the sludge solids entering the tank must be able to settle through a solid layer of any concentration between that of the settling tank feed and of the underflow which is recycled to the aeration tank. Therefore, sufficient tank surface area must be provided to allow the solids to pass through this concentration layer established in relation to a desired underflow concentration and an allowable depth of the sludge blanket.

A limiting factor to underflow concentration is the rate and nature of the biological decomposition in an anaerobic environment as in a clarifier. This factor is intimately related to the chemical nature of the waste and to the loading characteristics of the sludge system as previously described. For example, an activated sludge from a food processing waste could not be maintained in a final tank for long periods due to its high activity and gas production. As a result, the maximum attainable sludge concentration was 0.4 to 0.7 per cent. By comparison, an activated sludge from a pulp and paper waste could be maintained for extended periods in the final settling tank due to its low activity and nongas forming properties; sludge concentrations as high as 3.0 per cent could be attained.

Flotation

The use of flotation for sludge-liquid separation permits a higher solids balance to be maintained in the system independent of sludge settling and compaction characteristics. Dissolved air flotation is based on the concept that, when the air pressure in equilibrium with a liquid is increased, the amount of air dissolved in the liquid is directly proportional to the increase in pressure resulting in a supersaturated solution. When the pressure is released the dissolved air rises in the solution in microscopic bubbles. These fine bubbles attach themselves to and are enmeshed in the sludge floc, exerting a buoyant force which lifts the floc particles to the surface. In general, the suspended solids remaining in the effluent and the concentration of solids in the floated sludge are related to the ratio of air released at standard conditions and to the quantity of solids present in the system.

Optimum results in activated sludge flotation are obtained by pressurizing clarified liquor and blending this with the mixed liquor in an inlet chamber. The ratio of pressurized water to mixed liquor depends upon the mixed liquor solids content, the pressure employed and the operating temperature. Optimum pressures vary from 40 to 60 lb per sq in; while optimum recycle rates will vary with the mixed liquor solids, but for most applications will range from 30 to 80 per cent. A retention period in the flotation unit of 20 to 40 min will insure complete separation. Flotation of activated sludges from various waste oxidation systems has shown a variation in recycle sludge concentration of 1.6 to 4.0 per cent. Effluent suspended solids content of less than 25 ppm is attainable in most applications.

Calculations for Plant Design

In order to simplify calculations, symbols and abbreviations are important tools. A few have been used in the foregoing presentation. Additional ones are required for the calculations necessary for a plant design. All these symbols are listed below in the order of their appearance in this paper. Many are reused throughout this section:

BOD = biochemical oxygen demand after 5 days' incubation at 20 C. This is 68 per cent of the total or ultimate oxygen demand

and is a measure of the available organic matter.

COD = chemical oxygen demand usually obtained by chromate oxidation and generally equals the total or ultimate oxygen demand.
ppm = parts per million = mg per liter
a = fraction of removed BOD that is synthesized
L_r = BOD removed, ppm
b = endogenous respiration rate, per cent per day
S = sludge solids, ppm
C = inert suspended solids
mgd = million gallons per day
Q = raw waste flow, mgd
Sr = return sludge
Sa = mixed liquor suspended solids
r = sludge recirculation ratio = R per Q
La = applied BOD, ppm
T = detention time in hours, based on $(Q + R)$
R = recirculated sludge flow, mgd
mg = million gallons
MLSS = mixed liquor sludge solids
MLVS = mixed liquor volatile solids
VS = volatile solids

For simplicity, no consideration will be given in this example of calculations for plant design to variability of waste flow or strength. It has been determined by tests that an organic waste has the following average characteristics:

BOD, ppm	980
Flow, mgd	0.94
Nitrogen, available, ppm	5.0

It is required that treatment remove 90 per cent of the BOD.

Design criteria. Laboratory and pilot plant studies gave the following information to meet the above requirement.

Return sludge = 8000 ppm = S_r (based on sludge compaction versus decomposition studies)
Mixed liquor volatile suspended solids = 2100 ppm
Mixed liquor suspended solids = 2500 ppm = S_a
Endogenous respiration rate = 8 per cent per day (based on volatile solids)

From these, the following calculations are made:

BOD loading = $0.94 \times 980 \times 8.34 = 7680$ lb per day (8.34 = lb per gal water)
BOD removed = $7680 \times 0.90 = 6900$ lb per day
Recycle ratio = $Sa/Sr - Sa = 2500/8000 - 2500 = 0.45$
Recycle flow = $0.45 \times 0.94 = 0.42$ mgd

(The computed recycle ratio assumes no solids in the raw waste. The build-up of active solids through the aeration system is neglected in the calculation).

Aeration tanks. A curve may be prepared showing BOD loading versus removal efficiency from experimental data (figure 3). An examination of this curve will show the maximum loading factor to maintain 90 per cent removal efficiency (1.0 lb BOD per day per lb sludge in this problem). Therefore:

$$\frac{\text{lb BOD applied}}{(\text{day})\ (\text{lb sludge})} = \frac{24\,L_a}{S_a\,T(1 + r)} = 1.0 \qquad (5)$$

$$T = \frac{24\,L_a}{1.0\,S_a(1 + r)} = \frac{24 \times 980}{1 \times 2500\,(1 + 0.45)} = 6.5\ \text{hr} \qquad (6)$$

Volume of aeration tanks

$$= \frac{(Q + R)T}{24} = \frac{(0.94 + 0.42)\,6.5}{24} = 0.37\ \text{mg} \qquad (7)$$

If contact stabilization is to be employed, data on the storage capacity must be obtained for design of the aeration tanks. The stabilization tank required will then be the difference between volume of the contact tank and the total aeration volume required for the process.

Air requirements. From laboratory or pilot plant studies, a relationship such as shown in figure 2 was derived assuming that no storage occurs.

$$\text{lb } O_2 \text{ per day} = (0.48 \times \text{lb BOD removed per day}) + (0.08 \times 1.42 \times \text{lb MLVS}) = (0.48 \times 6900) + (0.08 \times 1.42 \times 0.37 \times 8.34 \times 2100) = 4050\ \text{lb} \qquad (8)$$

From which rate of oxygen utilization is obtained:

$$\text{oxygen utilization rate} = \frac{\text{lb } O_2 \text{ per day}}{V \times 8.34 \times 24}$$

$$= \frac{4050}{0.37 \times 8.34 \times 24} = 55\ \text{ppm per hr} \qquad (9)$$

Sludge Production

From theoretical considerations that the ultimate BOD of a waste equals the sum of the oxygen utilized and the sludge produced by microbial growth (figure 4), the following equation can be developed:

$$\text{BOD ultimate removed} = O_2 \text{ utilized} + \text{sludge produced} \qquad (10)$$

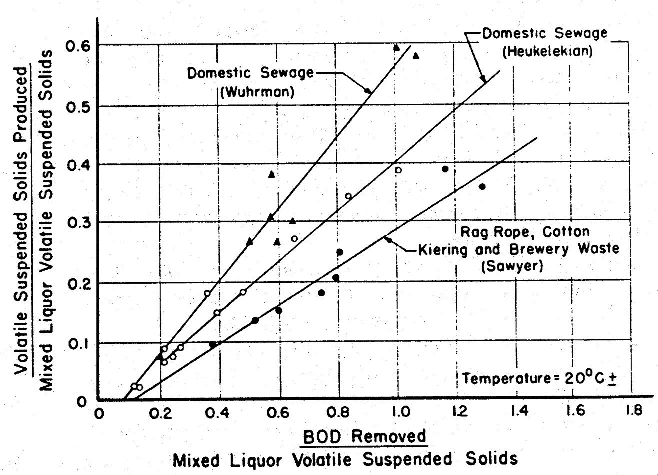

FIG. 4. Relation between BOD removal and sludge production in activated sludge process.

Substracting (8) from (10), converting to 5-day BOD units and introducing suitable conversion factors yields

$$\text{lb VS per day} = 0.70 \times \text{lb BOD removed per day} - 0.08 \times \text{lb MLVS}$$

where 0.7 is the fraction of 5-day BOD removed converted to sludge

$$= (0.70 \times 6900) - 520$$
$$= 4300 \text{ lb per day}$$

total solids produced $= 4300/0.85 = 5050$ lb per day where 0.85 is the volatile fraction of the sludge.

Nutritional Requirements

Experimental studies show that the critical nitrogen content = 7 per cent of the net biological solids:

Total nitrogen required $= 0.07 \times 4300 = 300$ lb per day
Nitrogen available in waste $= 5$ ppm $= 40$ lb per day
Required nitrogen $= 260$ lb per day

The phosphorus requirement may be similarly computed.

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